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# The effect of pes planus on the biomechanics of the lower extremity, balance, fall risk, and performance

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**Abstract**

**Introduction.** The study aim was to compare lower extremity dominance, subtalar angle, balance, fall risk, and performance in younger adults with and without pes planus.

**Methods.** A total of 80 physically active subjects participated in the study: 39 patients with flexible pes planus and 41 asymptomatic individuals. Arch height was assessed with the navicular drop test, the subtalar joint angles were determined with a goniometer, balance assessments were performed with the Biodex Balance System, and performance was evaluated with the single-leg jump and vertical jump tests. Furthermore, the strength of the gluteus medius muscles was measured with a dynamometer.

**Results.** A significant difference was demonstrated for the subtalar angles (right and left), as well as the single-leg jump and vertical jump test results between asymptomatic subjects and those with pes planus ($p < 0.05$).

**Conclusions.** It can be concluded that there was a decrease in the subtalar angle and performance in young adults with pes planus compared with asymptomatic participants. This finding suggests that prophylactic measures should be taken before the effects are seen in young adults.

**Key words:** arch height, pes planus, limb dominance, balance, fall risk, performance

## Introduction

Flexible pes planus is a common foot health problem that occurs as a result of decreased medial longitudinal arch height [1]. The deformity is observed to be transferred to the proximal part of the foot by varus of the calcaneus, with excessive pronation of the foot. It was found that the midfoot collapsed with weight, the height of the longitudinal arches decreased, and the stresses in the medial part of the foot increased [1, 2].

It is emphasized that pes planus changes the angulations in the hindfoot [3], causes instability in soft tissues, and leads to problems such as tibialis posterior insufficiency [3, 4]. These changes, which occur in the foot posture, are not limited to the foot and ankle, but reach the proximal part of the lower extremity. Foot posture is considered as a risk factor for lower extremity injuries [5]. Structural features of the foot influence the foot function [6]. Foot posture and problems within the foot affect the biomechanical distribution and loadings in the lower extremity, and this causes compensations in walking and daily life activities. With this compensatory mechanism, degenerative changes in the joints are accelerated because the joints are loaded in an inappropriate position [7, 8].

Extremity dominance is defined as an imbalance in muscular strength and an increased dynamic control of an extremity during an activity. As in the upper extremity, dominance is also determined for the lower extremity. This situation shows its effect as symmetric or asymmetric, especially during walking. It has been stated that the dominant lower extremity is used primarily and is subjected to more loading during activities. Meanwhile, the non-dominant lower extremity is used for providing stabilization and balance [8, 9].

A relationship was found between lower extremity dominance and injuries in individuals with high activity, such as footballers [10]. Another study demonstrated that dominance was related to the arch structure and gender [11, 12].

In the studies conducted, dominant and non-dominant lower extremities have been evaluated, but no difference has been observed between the 2 extremities [4]. Research presented in the literature has generally focused on the upper extremity dominance or on joint range of motion, postural control, or muscular tension in the lower extremity [13]. There is a lack of research concerning the lower extremity dominance and its effects on muscle strength, balance, and performance in younger adults with pes planus. We did not find any studies on the impact of lower extremity dominance on pes planus [9]. Our study aimed to compare lower extremity dominance, balance, fall risk, subtalar angle, and performance in younger adults with and without pes planus.

## Subjects and methods

### Participants

A total of 80 individuals (41 asymptomatic, 39 with pes planus) who were receiving education or working at Kırıkkale University were included in the study. Their average age was 21.30 ± 2.07 years. Flexible pes planus was diagnosed with the navicular drop test result exceeding 10 mm [11, 12]. The

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demographic data of the participants were recorded. The assessments were performed by a physiotherapist.

Individuals who volunteered to participate in the study, who were under 25 years of age, and weighed less than 150 kg were enrolled in the study. Subjects who had a history of trauma or surgery in the lower extremity in the previous 6 months, who could not walk independently without a walking aid, who had a visual impairment, and who suffered from a neurological or systemic disease were not included in the study.

The feet which the individuals used while hitting a ball were determined as their dominant lower extremities, and the feet from which they received support during standing or hitting a ball were determined as their non-dominant lower extremities [11]. The presence of pes planus was assessed with the navicular drop test, the subtalar joint angle was determined with a goniometer, balance assessment was performed with the Biodex Balance System (Biodex Inc., Shirley, NY, USA), and performance was evaluated with the single-leg jump and vertical jump tests. Furthermore, the strength of the bilateral gluteus medius muscles was measured with a hand dynamometer (baseline push-pull dynamometer; Digital Hydraulic, New York, USA).

### Navicular drop test

The arch height of the subjects was assessed with the navicular drop test [7, 12]. To evaluate the amount of navicular drop, the navicular tubercle was marked with a pen while the participant was sitting with bare feet in a chair; in both feet, the height of the navicular tubercle from the ground was determined with a tape measure. Then, the subject was asked to stand up. The height of the navicular tubercle from the ground was measured again in the position with full weight on the feet. The expression of the distance between both heights in millimetres (mm) was recorded as the amount of the navicular drop [12].

### Subtalar angle measurement

The subtalar joint angle was measured with a goniometer. The calcaneus posterior tubercle of an individual was matched with the pivot point of the goniometer. The fixed arm was placed parallel to the calcaneus and perpendicular to the ground. The movable arm was located on the traction line of the Achilles tendon. The narrow angle between the fixed and movable arm observed on the goniometer was recorded as the subtalar angle [13, 14].

### Balance assessment

The Biodex Balance System (Biodex Inc., Shirley, NY, USA) was used for balance assessment. The Biodex balance device consists of a movable platform that allows the participant to move forward, backward, and sideways, besides standing still. Among the balance indices taken, the whole index is considered as the best indicator for balance skill. A high whole index value indicates that the loss of balance is high. Balance scores of 0° imply the maximum possible balance. The platform has a mobility of 0–12°; 12 denotes the most stable platform, 0 forms the most mobile platform. In this study, the static balance and fourth-level dynamic balance tests were used. The tests were performed in the double-foot and standing straight position. Double-foot balance tests were carried out for 20 seconds with rest intervals of 10 seconds and 3 repetitions. Before the tests, a 10-second test with 1 repetition was made to provide the adaptation of the individuals to the static and dynamic balance tests and to ensure that they recognized the tests. The participants were asked not to move or speak during the test. The tests of the subjects who lost their balance were restarted [15, 16].

### Single-leg jump test

Single-leg jump tests are designed to assess functional performance in injured lower extremities. These tests require muscle strength, neuromuscular coordination, and joint stability in the lower extremity [17]. A tape measure is placed on the ground for the single-leg jump test. The individual should land on the ground without losing their balance with the leg they jumped on or without stepping on the other leg. The patient applies the test 3 times for each leg. The jumping distance is measured from the heel. In the case of losing balance, the jump is repeated. The individual is allowed to rest for about 30 seconds between jumps. They can use their arms to maintain balance during the jump [17, 18].

### Vertical jump test

The distance that the participants could jump vertically was measured with the vertical jump test [19]. The individuals were asked to jump with maximum force by taking power in a way that their knees flexed at 90° while their hands were on their waists. The distance that the subject jumped was visually determined and recorded with a meter hung on the wall. The individuals were asked to jump 3 times, and the average result was calculated and recorded [19, 20].

### Muscle strength assessment

The strength of the bilateral gluteus medius muscles was measured with a hand dynamometer (baseline push-pull dynamometer; Digital Hydraulic, New York, USA). During the evaluation, while the individual forced each muscle separately in the appropriate direction, the physiotherapist tried to break the force by opposing them. Meanwhile, the measured amount was determined in numbers on the dynamometer screen. The assessments were repeated 3 times and averaged. All measurements were performed by the same physiotherapist [21].

For the gluteus medius, while the patient is in the side-lying position, stabilization is provided by taking the lower leg to hip-knee flexion. While the physiotherapist provided stabilization over the pelvis with one hand, they applied force slightly above the knee to break the hip abduction movement with the dynamometer in their other hand. At the moment when the movement was broken, the value on the dynamometer was recorded. The test was repeated 3 times [21, 22].

### Statistical analysis

Statistical analyses were carried out by using the SPSS software for Windows, version 22 (IBM Corporation, Armonk, NY, USA). Demographic data and the collected parameters were presented as median, minimum, and maximum for non-normally distributed variables. The Mann–Whitney *U* test served to compare the groups for sociodemographic parameters. All statistical analyses were set *a priori* at a level of $p < 0.05$. Kolmogorov-Smirnov tests were used to assess the normality of distributions. For paired comparisons between the groups, the Mann–Whitney *U* test was applied. The general characteristics of the subjects were presented as means and standard deviations by using descriptive statistics. The sample size was calculated with the Raosoft online sample size calculator, with an error > 5%, and 3% for pes planus incidence.

## Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Non-Interventional Research Ethics Committee of Kırıkkale University (decision No.: 2018.10.13).

## Informed consent

Informed consent has been obtained from all individuals included in this study.

## Results

The demographic characteristics of asymptomatic individuals and those with pes planus were compared. No statistically significant difference was determined between the 2 groups ($p > 0.05$) (Table 1).

A statistically significant difference was found between the subtalar angles (right and left), as well as single-leg jump and vertical jump test results of asymptomatic individuals and those with pes planus ($p < 0.05$). There was no difference in the lower extremity dominance, balance, fall risk, or gluteus medius muscle strength between individuals with pes planus and asymptomatic subjects ($p > 0.05$) (Table 2).

## Discussion

In this study, we compared the subtalar angle, lower extremity dominance, balance, and performance in individuals with and without pes planus. Both the dominant and non-dominant extremity performance and subtalar angles were found to be lower in individuals with pes planus. It was observed that the levels of balance, lower extremity dominance, muscle strength, and fall risk were similar. The study is one of the few ones comparing lower extremity dominance in younger adults with and without pes planus.

In many recent studies, it has been emphasized that any loss of force in the foot structures or a factor affecting force production may negatively influence balance in both anteroposterior and mediolateral directions, leading to a fall risk increase [4, 6]. Many studies have demonstrated that pes planus affects force production and foot posture in foot

Table 1. Demographic features for the pes planus and asymptomatic groups

| Characteristics | Pes planus ($n$ = 39) Median (min-max) | Asymptomatic ($n$ = 41) Median (min-max) | $p$ | Cohen's $d$ |
|---|---|---|---|---|
| Age (years) | 22 (19–27) | 21 (18–27) | 0.856 | 0.02 |
| Height (cm) | 165 (152–182) | 164 (160–180) | 0.521 | 0.10 |
| Weight (kg) | 58 (43–92) | 59 (46–85) | 0.951 | 0.03 |
| Body mass index (kg/m$^2$) | 20.88 (17.36–32.72) | 22.23 (17.01–28.44) | 0.194 | 0.14 |
| Lower extremity right, length (cm) | 86 (76–101) | 87 (68–97) | 0.494 | 0.03 |
| Lower extremity left, length (cm) | 86 (77–101) | 86 (68–97) | 0.275 | 0.11 |
| Number of subjects (female/male) | 30/9 | 31/10 | 0.892 | 0.01 |

Mann–Whitney *U* test $p < 0.05$

Table 2. Mann–Whitney *U* test for the comparison of dominance, overall stability, anteroposterior balance, mediolateral balance, fall risk, subtalar angle left and right, muscle force, and performance

| Variables | Pes planus ($n$ = 39) Median (min-max) | Asymptomatic ($n$ = 41) Median (min-max) | $Z$ | $p$ | Cohen's $d$ |
|---|---|---|---|---|---|
| Dominance ($n$) | 38/1 | 37/4 | –1.320 | 0.187 | 0.14 |
| Overall stability index | 0.40 (0.10–7) | 0.50 (0.20–8.20) | –0.691 | 0.490 | 0.07 |
| Anteroposterior balance | 0.40 (0.10–7) | 0.30 (0.20–8.20) | –0.264 | 0.792 | 0.02 |
| Mediolateral balance | 0.20 (0.00–3.00 | 0.20 (0.10–4) | –1.049 | 0.294 | 0.11 |
| Fall risk | 0.6 (0.20–8.00) | 0.60 (0.10–7) | –0.378 | 0.705 | 0.04 |
| Subtalar angle right | 7 (2–16) | 10 (3–24) | –2.993 | 0.003* | 0.33 |
| Subtalar angle left | 7 (2–10) | 9 (2–18) | –4.819 | 0.000** | 0.54 |
| Gluteus medius right | 246 (200–422) | 240 (121–391) | –0.313 | 0.714 | 0.03 |
| Gluteus medius left | 266 (134–426) | 239 (149–360) | –0.915 | 0.360 | 0.10 |
| Single-leg jump left | 104 (65–150) | 121 (85–185) | –2.089 | 0.037* | 0.23 |
| Single-leg jump right | 106 (63–170) | 116 (77–194) | –2.349 | 0.019* | 0.26 |
| Vertical jump | 23 (17–40) | 25 (17–41) | –2.364 | 0.018* | 0.26 |

** $p < 0.01$, * $p < 0.05$

structures [23, 24]. El-Shamy and Ghait [25] highlighted that in flexible pes planus adolescent females, there is a decrease in dynamic balance parameters at level 6–8 of the Biodex Balance System (anteroposterior, mediolateral, overall stability index). Al Abdulwahab and Kachanathu [6] found that foot posture was associated with dynamic balance but not static standing balance in healthy young adults. As in this study, we also showed that individuals with and without pes planus exhibited similar static and dynamic balance scores. But some studies in older populations report effects on balance and postural stability [26]. These are thought to arise with postural adaptations in the musculoskeletal system, which are observed as a result of external factors, such as visual, auditory, somatosensory, and other proprioceptive stimuli during balance assessment [25]. Therefore, we believe that this study should be repeated in bigger samples and different populations, such as elderly [26] individuals, to determine the impact of pes planus on dynamic balance and fall risk. This would help take prophylactic measures before the effects are seen.

The low medial longitudinal arch structure in individuals with pes planus causes many mechanical insufficiencies [25]. Some of these are the angulations observed in the subtalar joint as a result of the increase in loading to the medial and thus the pronation of the foot. Excessive foot pronation together with pes planus causes biomechanical changes in the ankle, knee, and hip joint [27, 28]. Agoada and Kramer [26] showed that the subtalar angle was correlated with excessive foot pronation and pes planus, as can be seen in this study. But they correlated these findings also with other angles in the foot and other radiographic measurements, like the calcaneal inclination angle. Individuals with pes planus have lower subtalar angle degrees than those without pes planus. This study reports a middle-level effect size in the left extremity subtalar angle: this is its novel contribution to the literature. The effect on foot in healthy young adults are confirmed with goniometric assessments and measurements of the navicular bone height in this study.

It is known that pes planus may influence the hip joint biomechanics, and the gluteus medius muscle may be affected owing to its stabilizing function [29, 30]. In the present study, it was thought that the gluteus medius muscle strength might have increased because of the rise in the need for stabilization in individuals with pes planus. It was observed that the right and left gluteus medius muscle strength was similar. Goo et al. [30] revealed improvements in the gait of individuals with pes planus resulting from the strengthening of hip muscles. However, they focused on the gluteus maximus, not gluteus medius. In turn, Kim et al. [28] followed up individuals with pes planus who applied orthosis and gluteus medius strengthening exercises; after 8 weeks, they found improvements in the subtalar joint and in the pressure distributions in the middle and lateral foot parts. In this study, similarity was observed in gluteus muscle strength in the dominant and non-dominant leg. This was thought to be caused by a small sample size and a lower effect size.

Strong foot muscles mean better performance, in addition to a more stable arch structure in the foot. As a result of the low medial longitudinal arch structure in pes planus, weakened foot intrinsic muscles owing to unstable and abnormal load distribution are mentioned. In this study, the performance of individuals with and without pes planus were compared, and a difference was found between the 2 groups. Açak et al. [31] demonstrated that the performance in pes planus could be improved with foot orthosis in healthy and young individuals. They evaluated performance with a 30-m sprint test, 12-minute Cooper test, and vertical jump test. The vertical jump test showed similar result also in this study. Açak et al. [31] stated that reorganization of foot structure in pes planus could improve performance, which corroborates our study.

## Limitations

The limitations of our study were that foot posture was measured in a static position, there were no assessments of foot muscle strength, and pes planus was only considered with a positive or negative result of the navicular drop test but no information was provided about pes planus degree. We did not evaluate the stage of pes planus; stage 3 or rigid pes planus could reveal differences better. Future research is recommended with larger sample sizes about this topic.

## Conclusions

Pes planus is a physical problem of the foot and the arch height, which affects foot function. It can be concluded that there was a decrease in the subtalar angle and performance in young adults with pes planus compared with those without pes planus. However, in future studies, the investigation of pes planus levels and foot muscle strength or rigid pes planus in individuals with different dominant lower extremities will provide the literature with a novel perspective.

We recommend the evaluation of balance, fall risk, and muscle strength in individuals with pes planus in older age groups and a consideration of the pes planus stage.

## Disclosure statement

No author has any financial interest or received any financial benefit from this research.

## Conflict of interest

The authors state no conflict of interest.

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